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Managing municipal wastes for energy generation in Nigeria

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ABSTRACT

More than being source of pollution, health and related hazards, municipal waste can be source of energy, useful raw materials and other resources, if properly managed. As the urban and peri-urban populations in Nigeria increase, there is a need to look into ways of sustainably managing the bound to be increasing wastes. This paper explores the options for managing municipal wastes and advances the discussion towards the derivation of energy and enhancing material recovery in Nigeria. The data for this review work were sourced from previously published works and other secondary sources. In concluding this review, a conceptual framework and policy propositions for changing the municipal waste management paradigm in Nigeria are presented.

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1. Introduction

This paper examines the Municipal Wastes (MW) management in Nigeria with a view of proposing plausible options for improving on the existing system for the purpose of energy generation and enhancing material recovery. The country's population is on the increase and so are the urban settlements. The July 2011 population estimate for the nation is about 160 million, which is projected to reach 390 million by 2050 [1]. Following the era of agricultural boom; with increased income from cash crops production and the subsequent discovery of petroleum, the country has witnessed a surge in the proportion of the population living in the urban centres. The populations of the urban and peri-urban centres in Nigeria have been increasing as the economic fortunes

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of the rural areas decline. As the number of opportunities for gainful employment and livelihood decline in the mainly agrarian rural areas, urban centres' populations blossomed. The proportion of the population in the urban centres has witnessed a leap from about 43% in 2000 to 51% in 2011 [1]. These considerable growths in the urban population indicate the growth in population density in urban centres – cities and towns.

The growing urban population density, improvement in life style, increase in income and consumption are factors that increase waste generation capacity in Nigeria just like in other countries [2,3,4]. As the volume of wastes increases so are the many problems associated with the lack of adequate waste management in many urban centres. The recurring waste problems in urban centres in Nigeria includes low capacity for waste management, disposal of waste in unauthorized dumpsites, disposal of waste into canals and water ways, waste burning in undesignated areas, among others. This paper attempts to examine the municipal waste management in Nigeria with a view to proffer options for MW management that would facilitate energy generation and material recovery.

2. Energy, population and wastes crisis in Nigeria

While there is an increase in waste generation in major cities across Nigeria, as the population grows, there is also a rising energy demand which is yet to be met as there is hardly any significant improvement in energy generation, distribution and access during the last decades. The net electricity generation in 2009 was 1829 mW a little over the 1761.6 mW level of 1999 [5]. This low energy generation is grossly inadequate for meeting the energy requirement of a population approaching 170million. This scenario is an indication of the existence of energy crisis in Nigeria. IEA [6] reports that electricity consumption per capita in Nigeria for the year under review was 126 kWh. This electricity consumption rate betrays the various plans and programmes for transforming the Nigerian economy to be among the top twenty in the world by the year 2020. This dire energy access situation further buttresses the National Bureau of Statistics – NBS [7] report that shows that about 70% of the Nigerian population depends on firewood as the main source of energy. This figure represents about 108million people depending on firewood for cooking and other agricultural processing activities. The energy crisis more-or-less remains the most critical development challenge facing Nigeria. Successive regimes and governments at the federal level have attempted to address the energy situation by planning and implementing various energy reforms and programmes. The huge investments in these projects have not yielded appreciable increase in electricity generation. The country also faces a subsidy burden of about N1.3trillion annually for transport and cooking fuels such as petrol, diesel and kerosene.

The energy situation described above exists in spite of the huge natural gas resources. WEC [8] estimates the Nigerian recoverable natural gas reserve to be 5292 billion cubic meters. Of these, only about 31.7 billion cubic meters is produced in 2008, representing about 0.5% of the total recoverable reserve. It is worth noting that nearly half of the natural gas produced is flared or re-injected into the crude oil production process. Apart from natural gas, Nigeria produces considerable amount of wastes ranging from municipal wastes, livestock wastes, industrial wastes and other agricultural wastes. The rate of wastes generation is increasing with the growing populations which are increasingly clustered into urban and peri-urban settlements. Harnessing these wastes through an integrated waste-to-energy programme has the potential to contribute significantly to the daily energy requirements in Nigeria. Waste management for energy generation can provide off grid and micro-grid energy alternative for municipalities, small, medium and large scale industries. Landfill CH_4 recovery, incineration of combustible waste and anaerobic digestion of sewage sludge, wastewater and other biodegradable wastes are techniques which are well advanced for energy recovery from wastes. Various developed and developing economies are already implementing advanced technologies for sustainable waste management for derivation of co-benefits such as energy and material recovery [9]. Denmark and Norway are good examples of countries with huge commercially viable oil and gas reserves, yet they have advanced the waste management for derivation of multiple benefits.

3. Municipal wastes contribution to energy mix across the world

Energy mixes constitute putting in place different energy systems as well as linking up with different suppliers of energy in meeting energy needs which allows consumer to make a flexible choice. Energy mix may also allow for a shift from one energy source to another when one source fails. Various factors have been driving the broadening and utilization of the energy mix across the world. Bousquet and Ivaldi [10] investigating the choice of energy mix in French dairy industry postulated that the need to be able to take advantage of the shift in energy prices led to the installation of multiple energy systems on farms. The availability of a wide mix of alternative energy systems allows for shifting from the costly to less expensive overtime. In Asia, the need to reduce the carbon foot print from fossil fuels consumption is driving the broadening of the energy mix [11]. In the case of hybrid automobiles, the use of a mix of energy is basically for the purpose of reducing the emission of greenhouse gases (GHG) and fossil fuel consumption [12]. Many countries are broadening their energy mixes due to factors ranging from economic, environmental and social considerations to geographical suitability. There is a rapid rise in the energy mix across the world.

This increase in the broadening of energy mix is seeing to the increase of contribution of fuels and feedstock from renewable sources to the energy generation mix for meeting the needs of growing urban population. In a number of countries, municipal wastes are playing major roles in expanding energy generation mix for meeting their energy requirements through anaerobic digestion, pyrolysis and gasification. Table 1 shows figures for various countries with functioning pathways for derivation of energy from municipal solid waste. From the table, the estimates of available municipal solid waste for combustion to generate energy or digestion for biogas production shows what countries with far smaller population to Nigeria are doing with their enormous wastes potentials. The utilization of waste for energy generation is an important paradigm shift in municipal waste management. Nigeria with a growing urban population and increasingly dense communities has great potentials for harnessing energy from municipal wastes.

The paradigm shift towards broadening energy mix can be seen as a prerequisite towards reducing the volume of wastes that end up in the landfills. This shift can also see to reducing the cost of production for materials that are recovered or recycled or reused as well as providing alternative livelihoods for those involved in the waste management chains, and serve as clean environmental solutions. The low level of industrialization of agricultural production and processing in Nigeria portends the availability of high proportion of organic components of the municipal waste, which are useful for feeding bio-digesters or as combustible feedstock for feeding power plants. Most food and materials consumed in Nigeria are still sold in the markets, shops or supermarkets

Table 1
Municipal wastes utilization for energy in some countries.
Source: Adapted from WEC [8], survey of energy resources. Units: MT=Million tonnes, TJ=Terajoules, kW=Kilowatts.

Country	Population +	MSW estimate (MT)	MSW use for combustion (TJ)	Total energy production (TJ)	Electricity from MSW (TJ)	Electricity generating capacity from MSW (kW)
Austria	8,414,638	2.4	16,421.0	30,270.0	9000.01;*	555,0001;*
Brazil	193,732,694	40.0	–	2311.0	924.0	41,870
Canada	34,996,000	11.9	1.7	–	–	211,187
Czech Republic	10,512,208	0.24	1966.0	2008.0	42.0	3000
Finland	5,421,827	2.2	2380.0	4610.0	2160.0	–
France	65,350,000	24.0	27,209.0	40,795.0	13,586.0	772,800
Germany	81,799,600	0.5	56.0	71.0	15.0	831
Japan	126,659,683	0.60	54,983,820	–	–	2,230,000
Jordan	6,508,271	2.0	18.5	3.5 $mm^3$2;**	18.5	1000
Monaco	36,371	0.07	72.0	98.0	26.0	2600
Netherlands	16,751,323	–	1085.0	11,381.0	10,296.0	–
Sweden	9,514,406	–	–	–	4990.0	282
UK	62,262,000	3.8	2108.0	9169.0	7061.0	375,900
US	314,873,000	254.0	20,833.0	75,088.0	54,255.0	2,669,000

* Include other biomass and MSW.
** Biogas from MSW. + Population estimate from 2010 to 2012 on Wikipedia [13].

unprocessed and unpacked. A few pilots and experiments for biogas projects for cooking gas generation have been undertaken in laboratories and location across Nigeria. Nevertheless, rather than stop at the pilot phase, waste to energy through bio-digestion or other improved and environmental friendly options ought to be a permanent feature of the Nigerian energy mix and waste management. Wastes are renewable resources whose generation is permanent feature of human society.

According to the WEC [8] survey, many countries, including Australia, Canada, and Finland, among others, have been generating gas at a large scale from landfill, wastewater treatment, sewage treatment plants in addition to combusting municipal waste for generating energy. Cities in Nigeria generate wide range of the categories of wastes including sewage, wastewater, sawmill wastes, wastes from markets and abattoirs and other mainstream wastes from households, commercial and institutional sources. The sustainable pathway for solving municipal wastes problems as well as the energy crisis is deploying the full range of wastes from highly populated locations into the generation of various forms of energy. Locations with higher spatial density of waste generation can have suitable alternative energy system in place for utilizing huge wastes generated. Examples include locations with a high concentration of livestock farms such as poultry, and sawmills.

4. Waste generation and emission of GHGs

There is a direct and indirect link between the emission of greenhouse gases (GHGs) and wastes generation, as well as management. Wastes contribute to the GHGs emission levels, and the inexistence of efficient waste management systems only exacerbates the level of emission from this source.

IPCC [9] posited that post-consumer waste contributes about 5% of the global greenhouse gas (GHG) emissions. The broad range of municipal waste including organic food and other degradable waste, plastics, combustible materials are major contributors to GHG emissions, urban pollution, indirect cause of flooding due to the mismanagement of wastes and the attendant blockage of canals, sewage channels and floodway. IPCC [9] reported that carbon emission from the incineration of wastes containing carbon (C9 such as plastic, synthetic textiles) account for minor emissions.

The management of waste in urban and peri-urban settlements in Nigeria account for considerable emission of carbon dioxide (CO_2) resulting from open incineration of waste. Considering the current approach of management of waste in Nigeria which includes non-differentiation, lumping, low level of recycling, low level of reuse of materials from wastes from urban centres, emission of greenhouse gases can only be higher. The process of recycling, reuse, recovery which ought to reduce the rate of wastes generation and the attendant GHG emission, is not currently well implemented in Nigeria. Though commercial recovery of methane from landfill as source of renewable energy is well advanced, the untapped methane emission from landfill has been projected to be on the increase in developing countries including Nigeria [9]. GHGs emissions are renewable energy that is not being harnessed.

Though existing technologies for landfill gas recovery for energy generation have been proven profitable in developed countries, such technologies are yet to be fully deployed in Nigeria. Of all the thirty six states capitals in Nigeria, only Lagos has commenced the implementation of gas recovery from landfill. Meanwhile, CPE [14] showed that landfill gas (LFG) recovery and utilization for electricity generation are economically feasible for the four sites studied in Ibadan and Abuja. IPCC [9] prescribed the implementation of MW management for gas recovery to benefit from the clean development mechanism (CDM) as a good solution to the lack of capital for deploying technologies for curbing emission from MW.

Opportunities exist for implementing CDM projects for MW GHG emission curbing through energy recovery. This can help in tackling waste problems in Abuja, Lagos, Port Harcourt and other cities and state capitals with population over 0.5 million. The CDM project currently being implemented in Nigeria, includes (1) the recovery of associated gas otherwise being flared at Kwale oil–gas processing plant, (2) the Ovade Ogharefe gas capture and processing project, and (3) the Lafarge Cement WAPCO Plc) blended cement project [15]. These projects situated in Delta and Ogun states Nigeria have a combined 5352.63 kt of CO_2 emission reduction annually. These three projects give Nigeria a low representation in the CDM market in Africa, particularly considering the population and status of the economy in the continent. Therefore, the implementation of MW management for GHGs emission reduction which can benefit from the CDM or other carbon trading should be explored.

Apart from the potentials for energy and material recovery, the sustainable management of the municipal waste for the derivation co-benefits is a strategy worth exploring for meeting the goals of the various international agreements and treaties that Nigeria has signed up to and ratified. Abila [16] identified United Nations

Table 2
Waste generation across major cities in Nigeria.

City	Population	Per capita waste generation (Kg/ppd)	Organic wastes component (%)	Combustible wastes component (%)	Daily waste generation estimate (Kg)	Reference
Lagos	9,123,200	0.63	68.0	21.0	5,747,616	[19,20]
Kano	3,519,500	0.56	43.0	50.0	1,970,920	[19,21]
Benin	1,051,600	0.43	78.7	13.1	452,188	[22]
Onitsha	1,001,000	0.53	30.7	53.9	530,530	[19,23]
Ile-ife	313,400	0.46	77.9	12.6	144,164	[24,25]
Akure	369,700	0.54	59.5	16.2	199,638	[24,25]
Ado-Ekiti	523,300	0.71	60.4	25.7	371,543	[24,25]
Abeokuta	698,100	0.6	57.8	34.9	418,860	[24,25]
Ibadan	3,670,400	0.71	64.9	24.1	2,605,984	[24,25]
Makurdi	249,000	0.54	49.2	17.3	134,460	[26]
Abuja	565,100	0.57	56.4	36.4	322,107	[27]
Maiduguri	971,700	0.25	25.8	29.5	242,925	[28]
Nsukka	100,700	0.44	56.0	34.7	44,308	[19,29]
Port Harcourt	1,190,600	0.6	39.4	29.9	714,360	[19,30]
Ilorin	756,400	0.43	38.3	26.0	325,252	[31,32]
Average	–	0.53	53.7	28.4	–	
National	**140,431,790**[a]	"	"	"	**74,428,848.7**	

[a] Population figure based on the 2006 national population census for Nigeria.

Framework Convention on Climate Change, Kyoto Protocol, Ramsar Convention, and Cartagena Protocol among the various international treaties which Nigeria has ratified, and the quest for meeting the goals serves as a driver for promoting biofuels in Nigeria.

5. Municipal wastes (MW) generation in Nigeria

5.1. Estimate of municipal wastes (MW) generation from previous studies

Nigeria currently does not have an actual estimate of the municipal waste generation from households, industries as well as other waste sources for all cities and towns across Nigeria, but a few studies in the past have attempted empirical estimates for various cities and towns. Table 2 shows the waste generation estimates for various cities from previous studies. Based on the factors alluded to by earlier studies, including population, level of urbanization, level of industrialization, socio economic status of the population as well as the preponderance of the commercial activities, there can only be an increase in waste generation in Nigeria as the country's population continue to increase at about 3.1% national rate and 5.5% rate per annum for urban centres [17,18].

According to Ugwuh [18], the estimate of waste generation per capita for Nigeria is about 0.49 kg per person per day. Based on the current population estimate, Nigeria is generating about 86 metric tonnes of wastes daily. Babayemi and Dauda [17] reported another estimate of 0.58 kg of solid waste per person per day for the entire country. From Table 2, we can deduce an average figure from the various reported waste generation data to have 0.53 kg of waste per capita for Nigeria. This translates into 74,428.85 t per day waste generation for Nigeria based on the 2006 population census.

As can be seen in Table 2, the waste generation capacity varies from state to state, as well as from city to city. Even for semi and low urban cities with low population and low level of economic activities, the waste generation capacities are considerable. The nonexistence of efficient waste management system still makes wastes serious environmental and health concerns in most of the cities and towns across Nigeria. From the daily waste generation estimate, we can infer that the total waste generated per month and per annum is huge resource. This huge level of wastes generated is a resource-mine for the recovery of materials and energy. With the average organic composition of municipal waste from the previous studies at about 53.7%, there is an enormous material for biogas production as well as composting for organic fertilizer production. The combustible components are also materials for pyrolysis and combine heat and power – CHP – energy generation.

5.2. Theoretical estimation of the waste and potential biogas generation capacity of States in Nigeria

Table 3 presents the theoretical estimation of the waste generation capacity and the potential biogas for the various States across Nigeria. The waste generation estimate is based on the average daily waste generation reported in previous empirical studies for cities in Nigeria. The biogas generation potential is estimated using the adjusted mathematical formula according to Adeoti et al. [33], specified as

$$Q_{mw} = V_{mw} \times \rho \times 100$$

where Q_{mw}=domestic solid wastes biogas generation potential (m^3/day), V_{mw}=quantity of municipal wastes (tons/day), ρ=biogas generation guide value for domestic solid waste given as 0.2740 m^3 of biogas/ton/day and 100=is a unit to scale-up the biogas estimate towards a more realist value.

The municipal wastes generation estimate for Nigeria, based on the 2006 population census yields 74,428.85 t per day. This figure is an 8.12% increase from the figure reported earlier by Adeoti et al. [33], who estimated the total municipal waste generation for Nigeria to be 68,380.00 t per day based on the 1999 population figure of 110million people. Because of the conservative estimate from the original formula used by Adeoti et al. [33], the potential biogas yield is multiplied by 100. The municipal waste generation for Nigeria based on the theoretical estimation yields 2,039,350.42 m^3/day of biogas. Kano and Lagos States have the highest biogas generation capacity of 136,525.50 m^3/day and 132,347.77 m^3/day. The biogas estimate represents huge volume of methane and other greenhouse gases that are currently untapped across Nigeria. Harnessing these biogas resources from municipal wastes as well as the organic wastes from other specific sources such as agricultural waste (from poultry and livestock rearing) will help curbing the health and environmental problems associated with the use of firewood, which is the predominant cooking fuel in Nigeria [34].

Table 3
Theoretical estimate of the municipal wastes and potential biogas generation capacity of States in Nigeria.

Zones	State/daily waste generation capacity (tons/day)/potential biogas (m^3/day)						
North-West	Jigawa 2311.33 63,330.47	Kaduna 3240.16 88,780.29	Kano 4982.68 136,525.50	Katsina 3074.84 84,250.60	Kebbi 1725.97 47,291.49	Sokoto 1962.42 53,770.26	Zamfara 1737.80 47,615.79
North-East	Adamawa 1684.84 46,164.71	Bauchi 2466.12 67,571.82	Borno 2210.69 60,572.77	Gombe 1253.47 34,345.11	Taraba 1216.24 33,325.09	Yobe 1230.31 33,710.48	
North-Central	Benue 2254.43 61,771.37	Kogi 1756.44 48,126.53	Kwara 1253.64 34,349.66	Nassarawa 990.77 27,147.09	Niger 2096.03 57,431.20	Plateau 1699.46 46,565.24	FCT 745.31 20,421.40
South-West	Ogun 1988.10 54,474.06	Ondo 1834.26 50,258.86	Osun 1810.99 49,621.08	Oyo 2957.87 81,045.74	Lagos 4830.21 132,347.77	Ekiti 1271.45 34,837.65	
South-East	Abia 1508.05 41,320.61	Enugu 1731.95 47,455.53	Anambra 2214.25 60,670.42	Ebonyi 1153.78 31,613.62	Imo 2081.61 57,036.07		
South–South	Akwa Ibom 2068.09 56,665.58	Bayelsa 903.39 24,752.97	C-River 1533.28 42,011.97	Delta 2179.60 59,720.93	Edo 1713.68 46,954.94	Rivers 2755.32 75,495.75	

Note: Estimate of municipal waste generation based on the average from studies referenced in Table 2 multiply by the state population.
Potential biogas generation based on formula and guide value (minimum biogas generation potential) specified in Adeoti et al. [33].

6. Municipal wastes characterization in Nigeria

There are different types of wastes generated in municipalities. These different wastes types come from divergent streams. In Nigeria, municipal wastes come from the normal as well as other specific sources. The ranges of normal include streams of wastes from households, restaurants, markets and other commercial sources. The other specific sources include wastes from farming, sawmilling or other industrial/manufacturing activities.

6.1. Typical characteristics of wastes

The characterization of waste is critical for the determination of the suitability of the various components of the municipal wastes for energy recovery. Municipal wastes in Nigeria constitute waste generated in municipalities – urban or peri-urban centres in the country. The ranges of municipal wastes in Nigeria come from different sources. MW in Nigeria constitutes mainly household refuse and wastes from commercial and non-commercial sources such as industries, markets, abattoirs, schools, hospitals and other institutions. The characterization of municipal wastes in Nigeria is as broad as the sources. The Federal Ministry of Environment as reported by Imam [27] characterised wastes from different districts of Abuja, Nigeria under the categories of paper, metal, glass, plastic, food remnant, textile, rubber and others – which include woods, sanitary pads, diapers and other wastes that do not fall under the previous broad categories. Other authors have characterized municipal wastes under different other categories.

Igoni et al. [30] characterized municipal solid wastes in Port Harcourt, one of the major cities in Nigeria, under two broad categories: organic which include food wastes, wood/leaves, paper, plastics, textile/rubber/leather and undefined miscellaneous organic, and inorganic which includes glass and metal. This categorization lumped combustible but non-organic waste such as plastic, textile, rubber and leather which cannot be used for aerobic or anaerobic digestion for biogas production under the broad organic category. Kofoworola [20] reported an analysis of municipal solid wastes in Lagos into vegetables/putrescibles, paper, textile, metal, plastic, glass, miscellaneous, bones and ashes/dust. The paper further highlighted the properties of the MSW which qualifies them for the various uses including compost making, paper recovery, and glass recovery among others. The properties identified include combustibility and biodegradability. These properties help in further differentiating the various organic and non-organic components of municipal wastes under the various categories appropriate for their use for energy recovery and generation.

Igbinomwanhia [22] characterized MSW in Mushin and Oredo local government areas of Lagos and Edo States of Nigeria into organic food waste, combustible wastes, non-combustible and wood ash. Typical municipal wastes in Nigeria, as it is globally, fall under the broad organic and non-organic categories. Within the organic category we have the easily biodegrade wastes components which include food wastes from a variety of sources including households, eateries, institutions, and the non-easily biodegradable which include papers, cardboards, and tetra packs. The biodegradable components of the organic wastes generated in municipalities in Nigeria are largely food waste, vegetables, and meal scrap [22,29]. The inorganic category includes components that are combustible such as plastics, rubbers, textile and the non-combustible components such as metal and glass.

The estimate of the organic and the inorganic components of the municipal wastes vary from city to city. From Table 2 above, we can deduce that the organic and combustible waste component of wastes in cities in Nigeria is 53.7 and 28.4% respectively. The organic component is basically biodegradable, while the combustible include paper, plastic, rubble and wood wastes, among others. The high component of MSW being biodegradable has been associated with the heavy dependence on home prepared meal [22]. The appropriate characterization of the municipal wastes in sync with the separation from the points of generation is important for meeting the goals of energy generation as well as material recovery.

Considering the increasing number of commercial eateries and small to medium food processing and service companies, the bulk of the MSW will still remain largely biodegradable because of the low level of industrialization of agricultural processing, particularly post-harvest processing. This indicates there is the need to put in place adequate measures for harnessing biodegradable wastes for aerobic and anaerobic digestion for biogas production. Harnessing the biodegradable wastes will help in reducing the harmful effects such as offensive odor, breeding point for diseases

and parasites, and other forms of pollutions. The large proportion of biodegradable component of MSW indicates there is a lower proportion of combustible component for pyrolysis and gasification. This indicates the need to prioritize the biogas generation or methane recovery technologies and techniques over incineration for CHP related electricity generation. Where there is an increase in plastic and other combustibles components of MSW, combustion or incineration for energy generation becomes a more appropriate technique for reducing landfill space, and attaining other benefits. Igbinomwanhia [22] reported an increase in the proportion of plastic and paper wastes in Benin metropolis and in Nigeria. Reasons for the increase in the plastic wastes includes the increase in the sales of products packaged with plastic and paper, particularly the retailing of portable water with polythene sachets. There is also an increase in the use of plastics as shopping bags across Nigeria. The abundance of the various wastes types necessitates the deployment of the appropriate energy generation techniques.

6.2. *Municipal wastes from other specific sources*

There is an increase preponderance of wastes from other specific sources such as sawmills, farms and abattoirs. Though there is currently no estimate for various wastes from these sources for cities across Nigeria, the abundance of these categories of wastes account the problems – such as offensive odor – associated with them obvious. The need to bring the production of the various products such as egg, meat, planks closer to the consumers has led to the surge in the number of industries that generate this category of wastes closer to urban areas in Nigeria. All across the major cities and towns, there are big sawmills producing timber products as well as poultries producing eggs and meat for the urban dwellers. These facilities generate humongous tonnage of wastes that currently are not accommodated within the existing municipal waste management systems in most cities. These wastes categories will require less processing and logistics in putting them to use for energy generation, particularly at the source points. As the population of the country increases, particularly in the urban centres, there is bound to be an increase in the generation of the other specific wastes. Rather than the current open air burning of sawmill wastes such as sawdust, wastes woods, and tree barks, these can be used as feedstock for gasification for energy generation. The organic and biodegradable waste from farms and abattoirs are suitable for feeding bio-digesters designed for generating biogas for direct use or for generating electricity.

7. Prevailing waste disposal and management system in Nigeria

The prevailing municipal waste management system in Nigeria involves the formal and informal participants. The formal participants include the governments and respective government agencies that are saddled with the waste management responsibilities in key urban centres. The governmental actors play key role in developing policies, drafting and enforcing legislations relating to wastes management. The lists of the formal participants include the ministry of environment at the federal and state levels, as well as the environment office at the local government areas (LGAs). The formal participants are responsible for the mainstream municipal waste management from waste collection, collection of waste rate: the mandatory waste charges paid by households in various towns and cities, developing and implementing policies as well as managing the operational and closed landfills. Other categories of formal participants are the private operators who are contracted for providing waste management logistics such as waste collection trucks, distribution of waste bins, excavation and management of landfills.

The informal participants include the various layers of scavengers and waste collectors through the waste chain. This include the scavengers that collect materials that can be recycle or reuse from the waste source points to those operating at the various landfills in big towns and cities. Other informal participants are the petty traders that are involved in the buy-back of useful materials such as glass bottle, rubber shoes, metals and other wastes categories that currently have recycling channels. The waste material buy-back in Nigeria involves the traders moving from house to house, town-to-town collecting materials and paying with cash, as negotiated or paying back through trade-by-batter with other products that could be useful or be of value to the person disposing of recyclable materials. Though the informal buy-back helps to cut back on the volume of wastes that go into the dump, different materials that are recyclable are currently not collected for recycling through this channel. There are a range of glass and metal bottles of drinks, wines and pharmaceuticals products that the informal buy-back does not have markets for, hence, these products are not collected.

Fig. 1 is a flowchart that captures the existing mainstream waste management in most cities and towns across Nigeria. Some towns that are not the capital cities or LGA headquarters do not enjoy waste management services from any of the formal participants – government agencies or private operators. These settlements largely use the illegal and inefficient waste disposal methods ranging from burning refuse at the backyard to disposal into gullies, rivers and streams. Different factors account for the poor or the absolute lack of waste management services across Nigeria [35,27]. Some of these problems include financial and logistical problems which account for nonexistence of waste management services in most towns. Organizing even a small scale waste disposal efficiently requires funds for staff salaries, equipment, and logistic costs, among others, which the current fiscal commitment at various levels of government does not support. Municipal solid waste disposal is a major concern in developing countries across the world, as high poverty, population growth, and high urbanization rates combine with ineffectual and

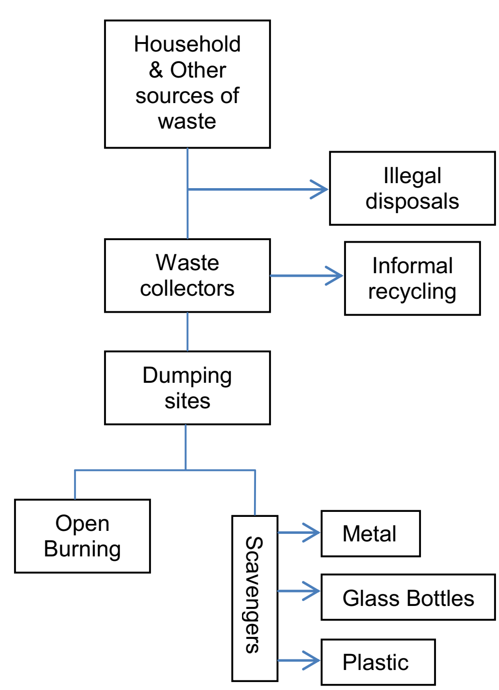


Fig. 1. Existing MW Management System in Nigeria.

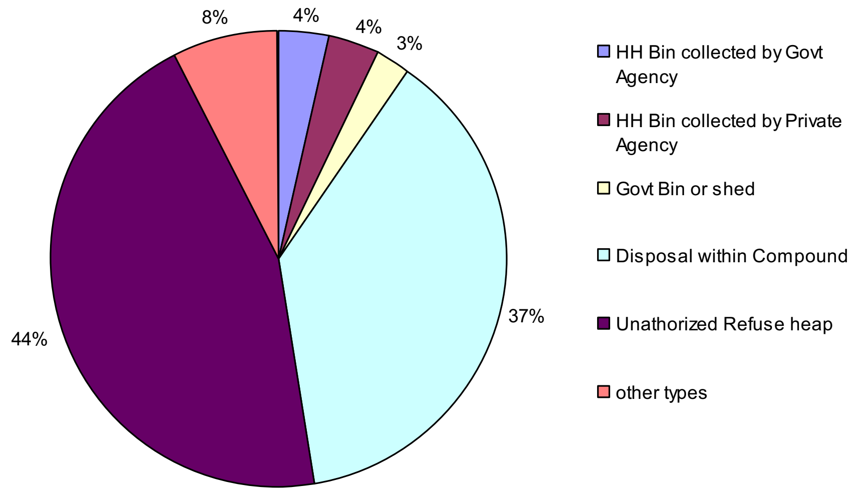


Fig. 2. Waste disposal methods in Nigeria (NBS, 2008). HH – Household.

under-funded governments hampers efficient management of wastes [21]. In most cities and large towns across Nigeria, solid wastes are not only heaped in huge quantities on refuse dumps but also thrown and made to lie around in piles on the streets and in small illegal dumps on any piece of unused land.

To ensure the recovery of energy, materials and ensure that co-benefits derivable from waste management is attained in Nigeria, there is need to rework existing waste management systems in cities, towns and villages across Nigeria. Every settlement should have a well-planned and run waste management system in place to ensure wastes are disposed in a sustainable manner. Fig. 2 shows the distribution of waste disposal mode across Nigeria from study undertaken by the Nigerian Bureau of Statistics in 2007.

Waste disposal within compound – mostly burned at the backyards – as well as the unauthorized refuses heap accounts for the disposal method for about 81% of the wastes generated in Nigeria. Though some states and cities have improved on waste management that allow for improve recycling, reuse, recovery, many other state are yet lagging behind. The low level of waste disposal through channels that can be considered as appropriate and less harmful to human and the environment portend that the incidence of direct emission of GHGs, indirect emission, pollution and associated health hazards can only be higher for Nigeria.

The prevalence of the unsustainable waste disposal mode in Nigeria can be explained by the fact that waste management as a public service is still largely a responsibility consigned to government and governmental agencies. Most of the agencies have inadequate funding as well as shortage of equipment, logistics and human resources needed to put up a more efficient wastes management service. The cultural attitude to waste streams generally may be playing a part in amplifying the waste management problems in Nigeria. Changing attitude and increasing perception of waste as valuable resource will help in enhancing waste management system in Nigeria. The informal participants and government agencies in a few states already recognized the value of waste through the improvement in the waste management for enhancing the recovery, recycling and reusing of wastes.

Key hindrances to sustainable waste management in developing countries include local availability of capital, the deployment of appropriate and truly sustainable technology [9]. The hindrances to sustainable waste management in Nigeria range from economic, social or cultural, technological to political. These hinder the deployment of appropriate waste management techniques and technologies for harnessing the multiple benefits derivable from an improved system. There is also the problem of lack of data on the estimate of normal and other kinds of wastes across Nigeria. Various past individual research efforts for estimating waste generation are grossly inadequately for making feasibility and projection for new projects. Improvement in waste data collation, availability and distribution is crucial for instituting needed change in the waste management sector in Nigeria. An improved estimation and forecasting of waste generation capacity will help in making an outlay of possible options for sustainable waste management and the derivation of multiple benefits. To fully ensure the derivation of energy and other useful materials from municipal waste in Nigeria, the prevailing wastes management systems need to be overhauled.

8. Proposing framework for energy recovery or generation from municipal waste in Nigeria

Overhauling the existing wastes management system in Nigeria will entail instituting processes and structures for best practices in waste management. The institutionalization of the best practices in waste management will entail bringing in various formal and informal participants to form a synergy, create a new system, adopting best practices and technologies. The best practices in waste management can be summarized as the use of the four Rs-strategies of reduce, reuse, recycling, and recovery for managing wastes. These best practices include innovations and technologies for implementing the re-use, recycling, recovery which help to reduce landfill waste volume and the need for more land [9]. Elements of the R-strategies include compositing of biodegradable components and incineration of combustible materials for energy generation. The application of these improved techniques and technologies require adequate planning and implementation of an integrated waste management by municipalities. Fig. 3 presents an illustration of a proposed framework for energy generation and materials recovery from municipal waste in Nigeria as an improvement on the existing system.

8.1. Municipal waste to biogas

The separation of waste from source points or the waste management companies will allow for the differentiation of wastes into the various categories based on characterization that will determine their appropriateness for energy recovery, recycling or other use. From the various past studies reported for Nigeria [20,25,27,29], organic wastes constitute over 50% for wastes from household and commercial sources in municipalities

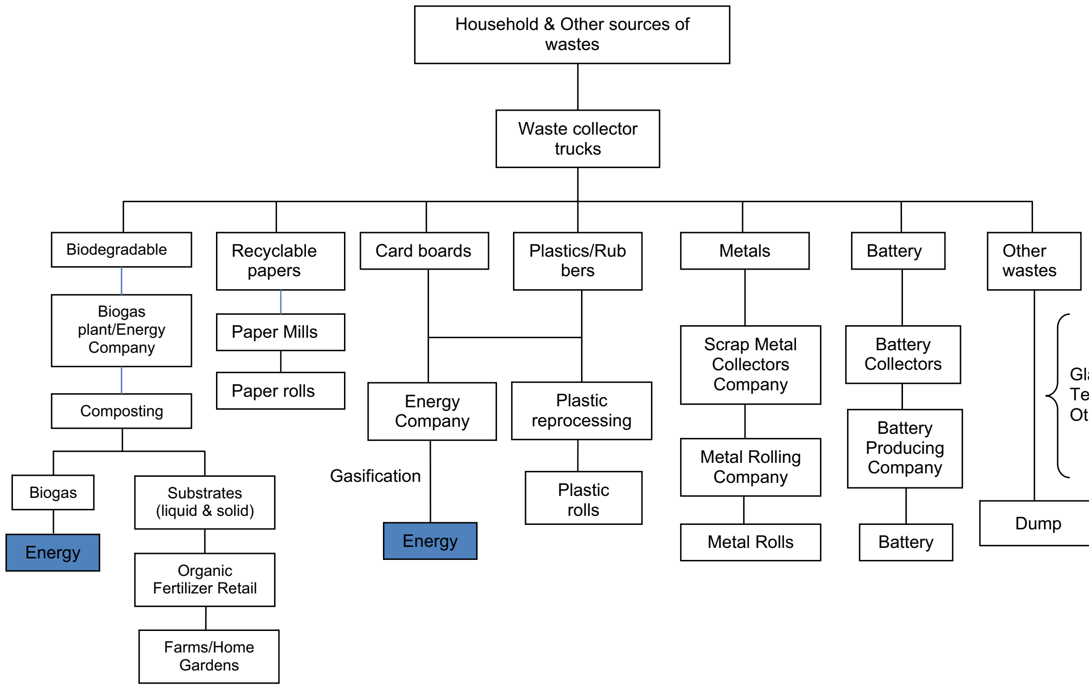


Fig. 3. Proposing MW Management System for Energy Generation and Material Recovery.

across the country. The organic wastes are mainly biodegradable materials that can be fed into bio-digester for biogas production.

Biogas production from MW is a cost effective, healthier and easy to managed alternative waste management system. The United Nations Development Programme (UNDP) energy report [36] mentioned the existence of substantial potentials for biogas systems and the growing installations of small biogas plants in African, Caribbean and Pacific (ACP) countries. Biogas production from anaerobic digestion of biomass or organic materials particularly from the MSW can be the next crucial innovation phase in the quest to solve electricity generation and access problem in Nigeria. Sufficient biogas generated from small to large scale biogas plant can be used for running gas turbines and generating electricity for remote and disconnected communities. Markard et al. [37] see biomass digestion for biogas production as a matured technology and a radical innovation in electricity generation because of its decentralized natured. The decentralization of electricity generation is already a common practice in Nigeria. With the poor supply of electricity to homes and business, standalone power generations from small to medium capacity generators are widespread across the country. Rather than fueling these generators with fossil fuels such as petrol and diesel, the use of biogas – cleaned and compressed – provides a greener alternative for Nigeria. Households and commercial centre with ample generation of biodegradable wastes can construct small unit bio-digesters for generating the biogas needed for fueling their generators when electricity supply from the main grid is cut-off. Closed landfills and bio-digesters constructed on dumpsites can be source of clean and compressed biogas for filling retail gas-cans. Where community-scale off-grid electricity generation is plausible, landfills and dumpsite in such localities can be the source of fuel for such projects.

Rather than individuals or households to purchase and maintain their electricity generators, medium to large scale generators can be installed as a mini-grid option which is fueled using biogas from such a community. This type of decentralized electricity system is a solution for the aging and less effective centralized grids from which Nigeria currently depends on for meeting industrial and household energy need. The community level mini-grid electricity generation can be made possible through biogas production for gas-fueling medium to large capacity generators that can run on gas. The applications of other energy recovery techniques and technologies from MSW can also help in developing and implementing off or micro-grid electricity generation programmes. Nigeria generates abundant biodegradable wastes that can be harnessed for the production of gas for the direct use in cooking, cooling, lightening. Adeyemi and Adeyemo [38] reported the availability of massive solid wastes from a local abattoir in Ibadan which is increasingly becoming nuisance. The scenario is the same in all major cities and towns across the country with increasing capacity for generating huge MW which currently poses major management challenge. The need for deploying more efficient management systems for the increasing wastes is made more compelling due to the increasing rate of urbanization.

8.2. Municipal wastes combustion for energy

Apart from the biodegradable components of municipal waste, there are considerable proportions of combustible materials that can be used for electricity generation. The bulk of combustible organic materials from commercial and other specific sources that cannot be recycled can be fuel for gasification or incineration to energy. Combustible materials from the mainstream waste and materials with high energy content such as the sawdust which currently have no use but burnt in the open can be channeled into electricity generation.

8.3. Material recovery from municipal wastes

The proposed overhauling of the existing waste management system in Nigeria will also provide for increasing the level of materials that can be recovered apart from benefit of electricity generation. As can be seen in Fig. 3, materials such as polyethylene terephthalate (PET) plastics, cans, rubbers, different metals (aluminum, copper, brass), bottles, and battery can be separated from source for facilitating recycling. Some of these materials already have buy-back mechanism with the informal participants

in the municipal waste management in Nigeria. A new framework should ensure that the informal participants harness their existing channels for meeting the bigger national goals for sustainable waste management. Government interventions – policies, laws, legislation, funds, equipments and training should be tailored towards enhancing their contribution to improving waste management.

9. Conclusion

Nigeria has a high potential for energy generation from municipal wastes. From the estimations based on previous studies and from the theoretical framework, Nigeria generates about 74,428.85 t of municipal wastes on a daily basis. The potential biogas generation from the huge municipal wastes is put at 2,039,350.42 m^3/day. Owing to the high percentage of organic matter component of municipal wastes in Nigeria, biogas potentials will remain very high. The increasing population and wealth of the middle class among other factors will continue to drive the growth in municipal wastes generation, necessitating the deployment of appropriate waste management techniques and technologies. The federal government of Nigeria as well as the governments at the states, local governments and municipalities must work towards facilitating the collection of reliable data on waste generation. A reliable country-wide database covering various themes on wastes is pivotal for sustainable waste management. More so, existing laws and mandates of the various formal participants in the waste management must be reworked to include the evaluation and deployment of municipal wastes management for energy generation and material recovery. This must form part of government policy towards sustainable management of municipal wastes in Nigeria. It is only when there is a close to correct figure for wastes generation that private investors can be better convinced on the existing potentials in municipal waste management in Nigeria, including waste-to-energy (WtE), material recovery, carbon trading, recycling, wastes export, among others.

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